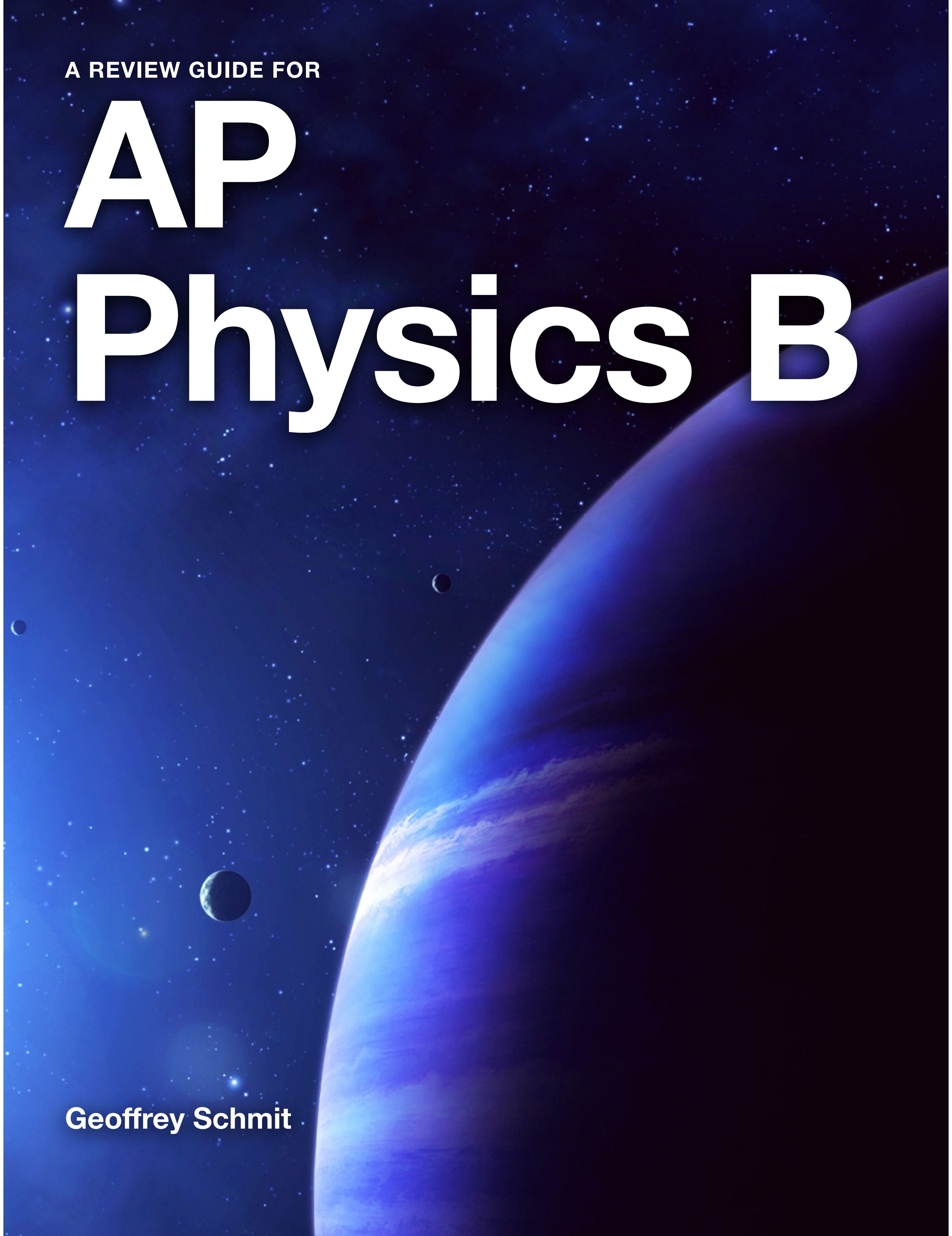
A REVIEW GUIDE FOR

AP Physics B



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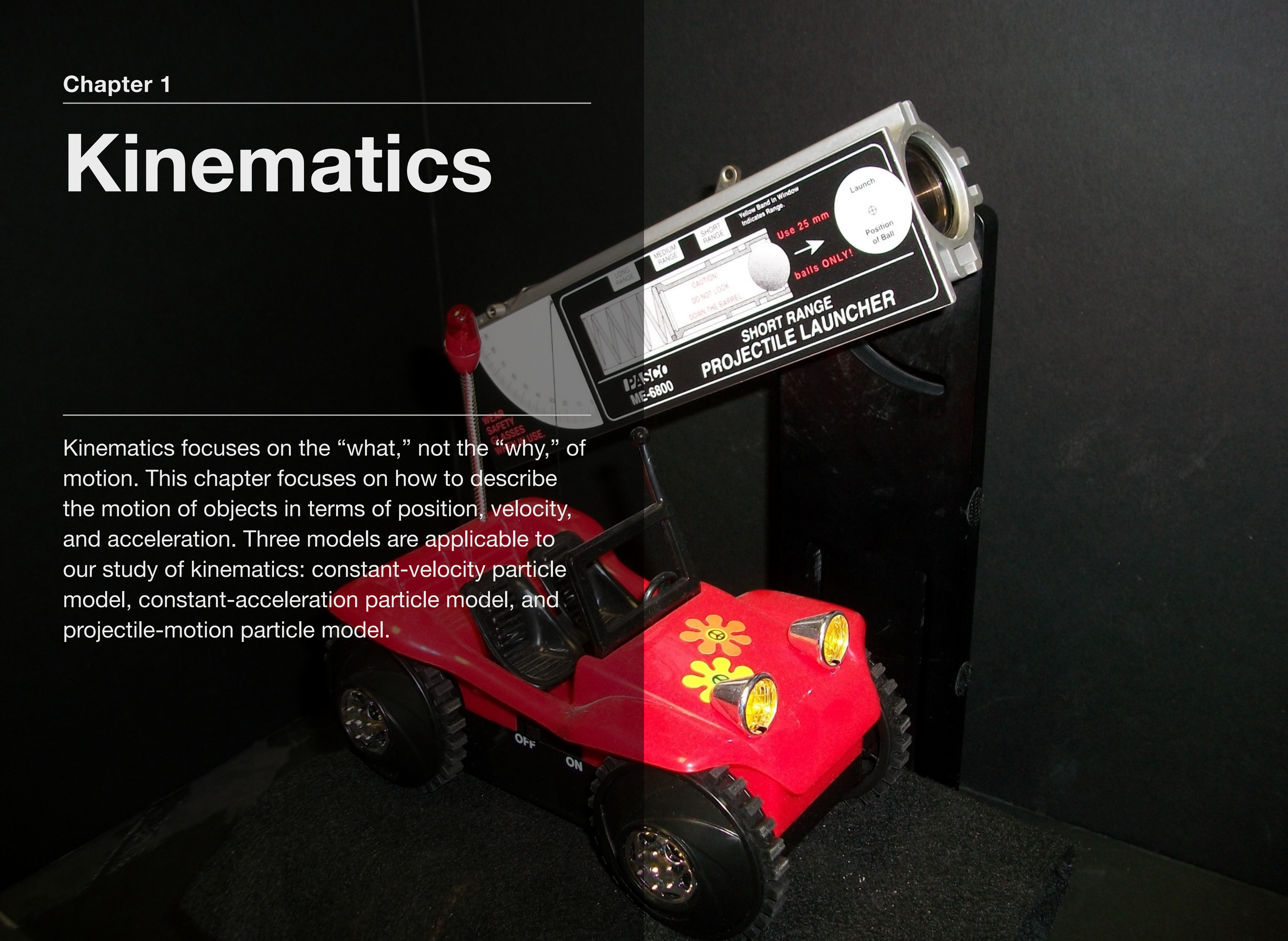
AP* Physics B

Chapter 1

Kinematics

Kinematics focuses on the “what,” not the “why,” of motion. This chapter focuses on how to describe the motion of objects in terms of position, velocity, and acceleration. Three models are applicable to our study of kinematics: constant-velocity particle model, constant-acceleration particle model, and projectile-motion particle model.



Section 1

Motion in One Dimension

MOTION IN ONE DIMENSION

a) **Students should understand the general relationships among position, velocity, and acceleration for the motion of a particle along a straight line, so that:**

(1) **Given a graph of one of the kinematic quantities, position, velocity, or acceleration, as a function of time, they can recognize in what time intervals the other two are positive, negative, or zero, and can identify or sketch a graph of each as a function of time.**

b) **Students should understand the special case of motion with constant acceleration, so they can:**

(1) **Write down expressions for velocity and position as functions of time, and identify or sketch graphs of these quantities.**

(2) **Use the equations $v = v_o + at$, $x = x_o + v_o t + \frac{1}{2}at^2$, and $v^2 = v_o^2 + 2a(x-x_o)$ to solve problems involving one-dimensional motion with constant acceleration.**

This section describes motion in one dimension, that is, straight-line motion. Two models are applicable to our study of motion in one dimension: constant-velocity particle model (CVPM) and constant-acceleration particle model (CAPM). Both models describe simply the object to that of a point particle. We will not focus on objects with non-constant acceleration.

Constant-Velocity Particle Model (CVPM)

The constant-velocity particle model (CVPM) describes the motion of point particle moving with a constant speed in a single direction. As we will review in a future chapter, objects move with constant velocity when they experience balanced forces.

Constraints and Simplifications

- objects are modeled as point particles
- objects move with constant velocity

Graphical Model

The CVPM is described graphically through position vs. time, velocity vs. time, and acceleration vs. time graphs.

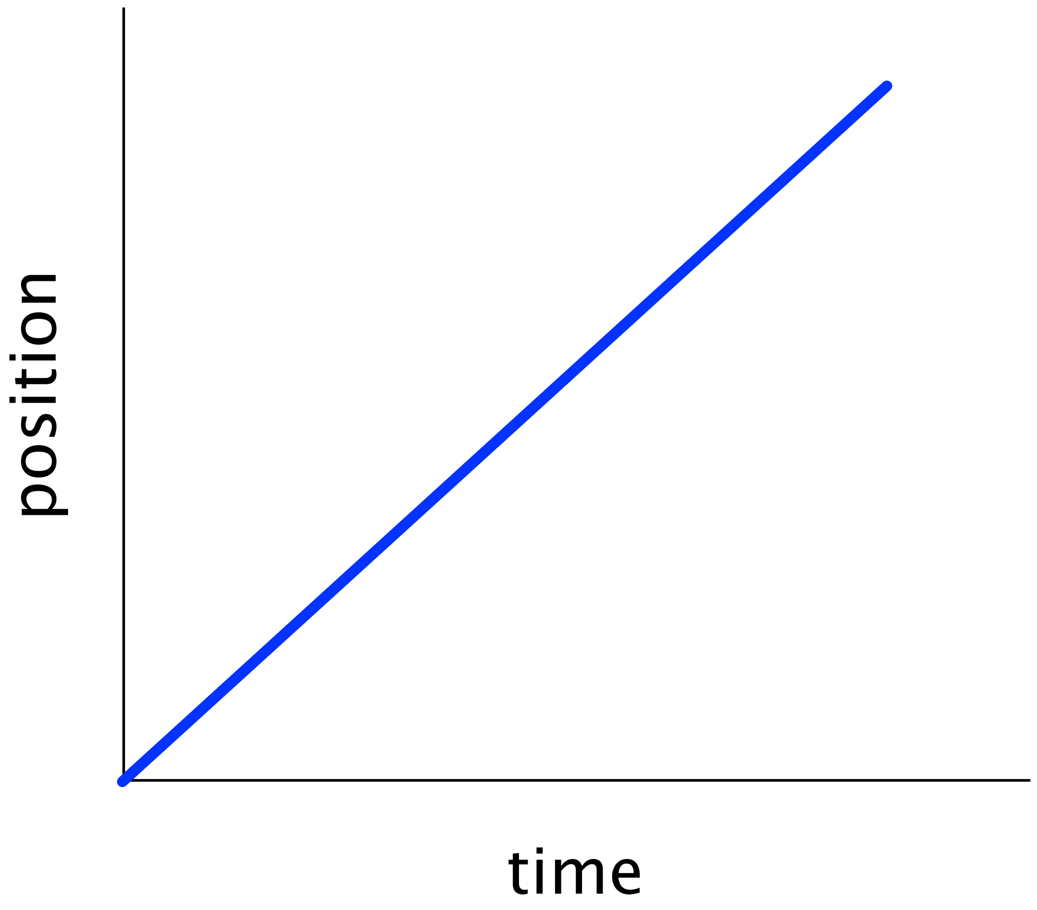


Figure 1.1 CVPM Position vs. Time Graph

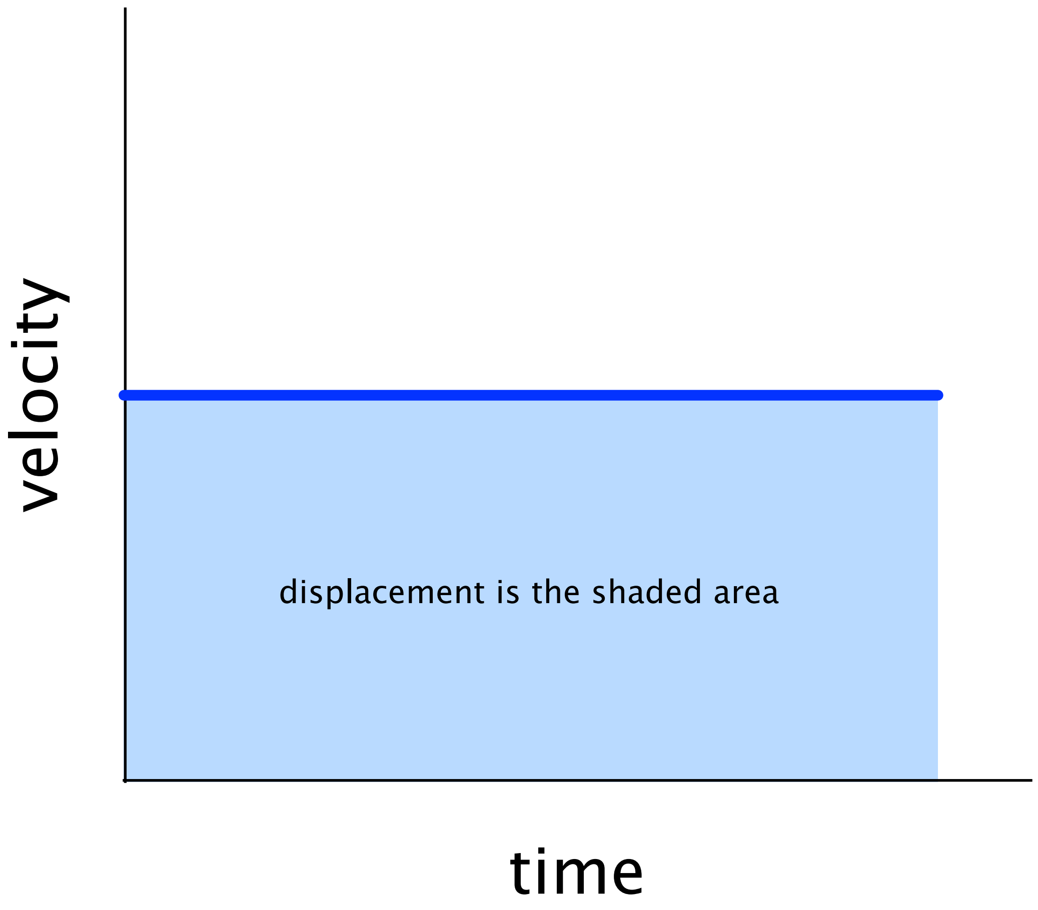


Figure 1.2 CVPM Velocity vs. Time Graph

The position at any time can be determined directly from the position vs. time graph (Figure 1.1). A positive value for the position indicates that the object is located in the positive direction relative to the origin; a negative value, that the object is located in the negative direction relative to the origin. The displacement for a time interval is determined by calculating the change in position for that interval. Note that the position vs. time graph shows a linear relationship. That is, the rate of change is constant. This rate of change of position, the slope of the position vs. time graph, is the velocity.

The velocity of the object is constant; therefore, the velocity vs. time graph (Figure 1.2) is a horizontal line. A positive value for the velocity indicates that the object is moving in the positive direction; a negative value, that the object is moving in the negative direction. The displacement of an object for a time interval is the area between the velocity vs. time curve and the horizontal axis. An area above the axis represents a positive displacement; below, a negative displacement.

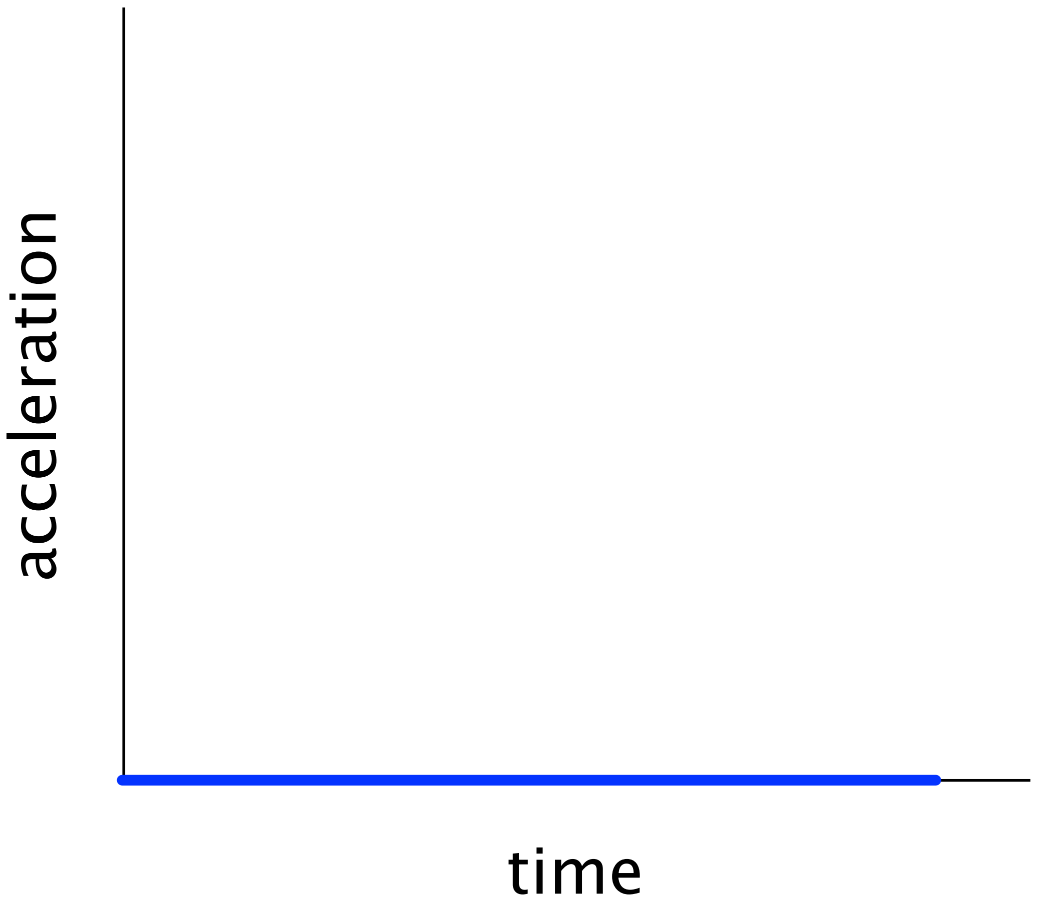


Figure 1.3 CVPM Acceleration vs. Time Graph

Since the object is moving with a constant velocity, the rate of change of the velocity, the acceleration, is always zero (Figure 1.3).

Mathematical Model

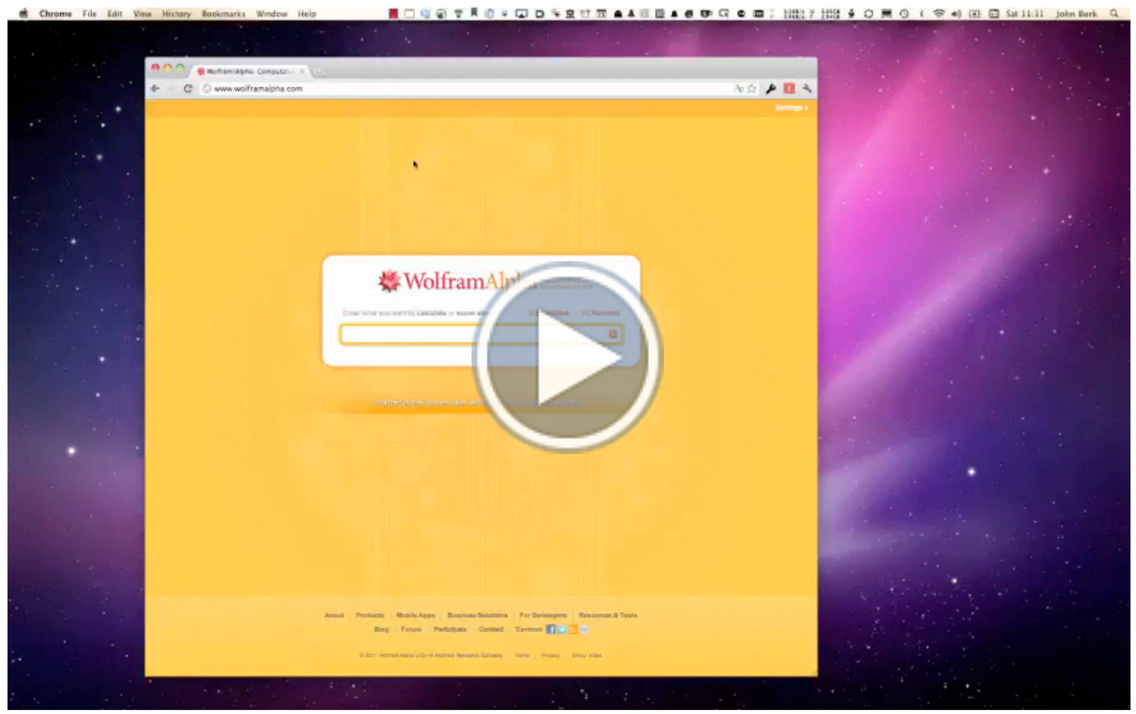
The mathematical relationship between position, velocity, time is simple for the CVPM.

$$v = \frac{\Delta x}{\Delta t}$$

v is the velocity of the object in units of meters/second; Δx is the change in position (the displacement) of the object in meters; and Δt is the time period, during which the change in position occurs, in seconds.

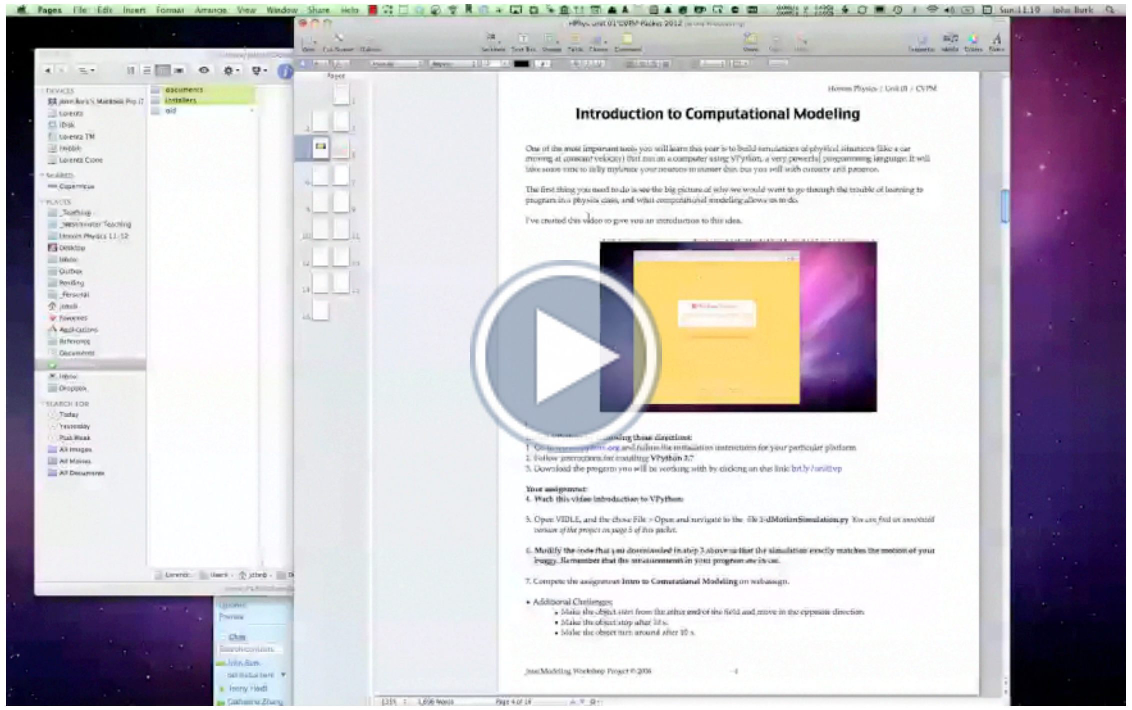
Computational Model

John Burk is a high school physics teacher and one of the pioneers bringing computational modeling to high school students. He created a wonderful introduction video for computational modeling (Movie 1.1).



Movie 1.1 CVPM Computational Model

We will reference and modify several computational models in this class. The models will be written in Python using the vpython and physutils packages to handle the animation and graphing for us. Mr. Burk also create a screen cast to introduce the first model for CVPM (Movie 1.2).



Movie 1.2 Computational Modeling Introduction

Download the CVPM computational model from our class web site and to explore computational modeling and the CVPM model.

Constant-Acceleration Particle Model (CAPM)

The constant-acceleration particle model (CAPM) describes the motion of point particle moving with a constant acceleration in a single direction. As we will review in a future chapter, objects move with constant acceleration when they experience a constant and unbalanced force.

Constraints and Simplifications

- objects are modeled as point particles
- objects move with constant acceleration
- the direction of the object's velocity and acceleration are along the same axis

Graphical Model

The CAPM is described graphically through position vs. time, velocity vs. time, and acceleration vs. time graphs.

The position at any time can be determined directly from the position vs. time graph (Figure 1.4). A positive value for the position indicates that the object is located in the positive direction relative to the origin; a negative value, that the object is located in the negative direction relative to the origin. The displacement for a time interval is determined by calculating the change in position for that interval. Note that the position vs. time graph shows a quadratic relationship. The instantaneous rate of change of position, or the slope of the position vs. time graph at a

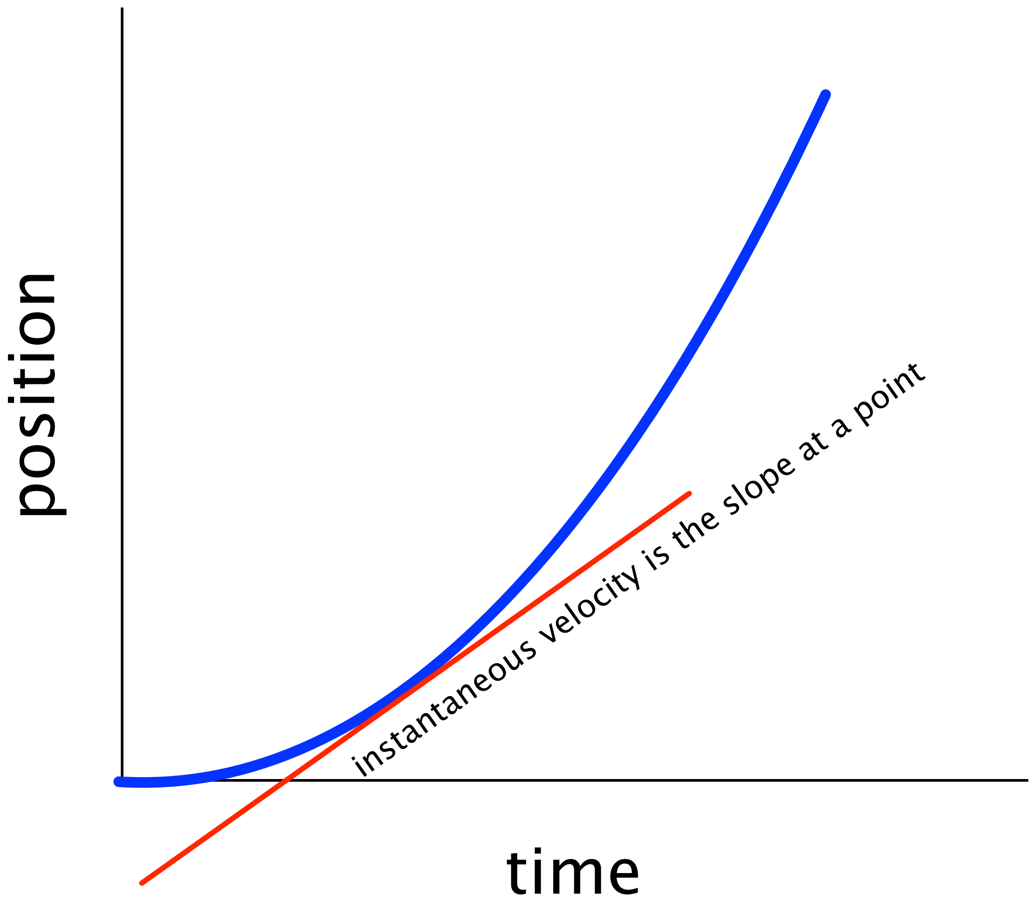


Figure 1.4 CAPM Position vs. Time Graph

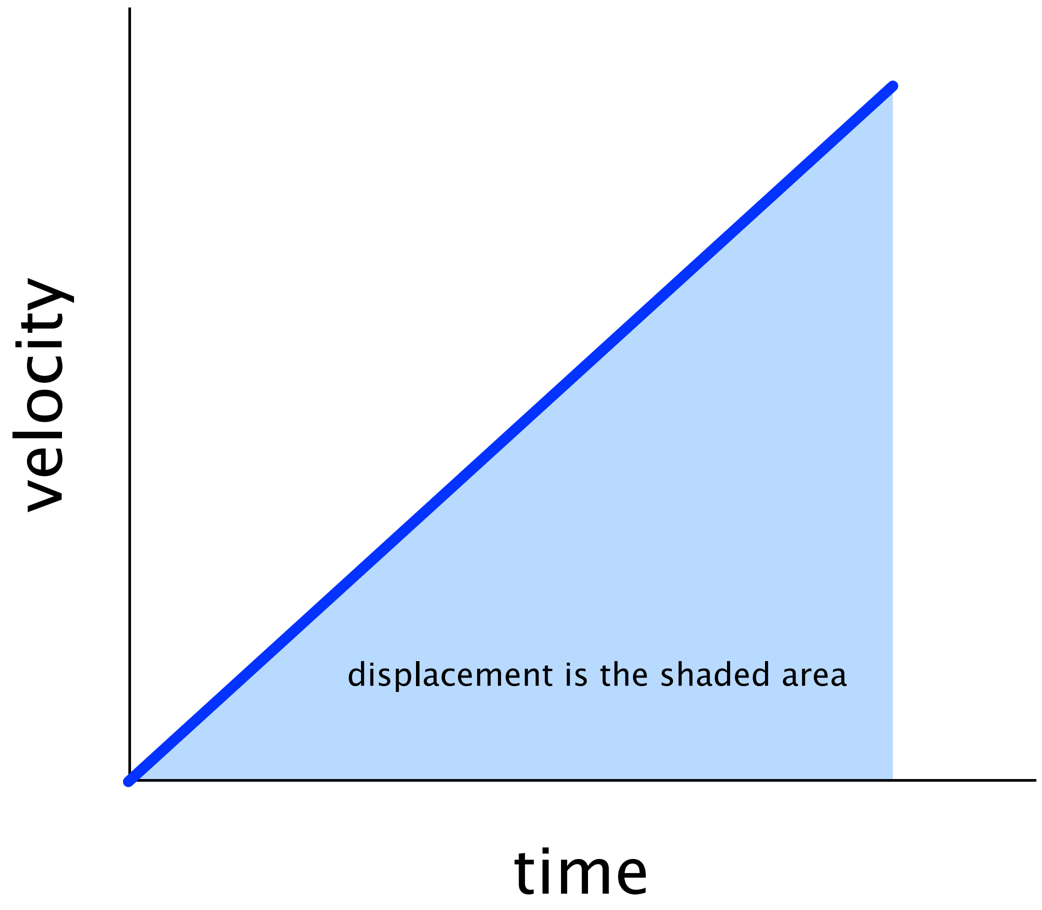


Figure 1.5 CAPM Velocity vs. Time Graph

given point is the instantaneous velocity. The slope of a line connecting two points on the graph is the average velocity for that time period.

The velocity at any time can be determined directly from velocity vs. time graph ([Figure 1.5]). A positive value for the velocity indicates that the object is moving in the positive direction; a negative value, that the object is moving in the negative direction. Note that the velocity vs. time graph shows a linear relationship. The displacement of an object for a time interval is the area between the velocity vs. time curve and the horizontal axis. An area above the axis represents a positive displacement; below, a negative displacement. The rate of change of velocity, the slope of the velocity vs. time graph, is the acceleration.

The acceleration of the object is constant; therefore, the acceleration vs. time graph ([Figure 1.6]) is a horizontal line. A positive value for the acceleration indicates that the velocity of the object is becoming more positive. Note that this doesn't necessarily mean that the object is moving faster. An object moving in the negative direction that experiences a positive acceleration will slow down. A negative value for the acceleration

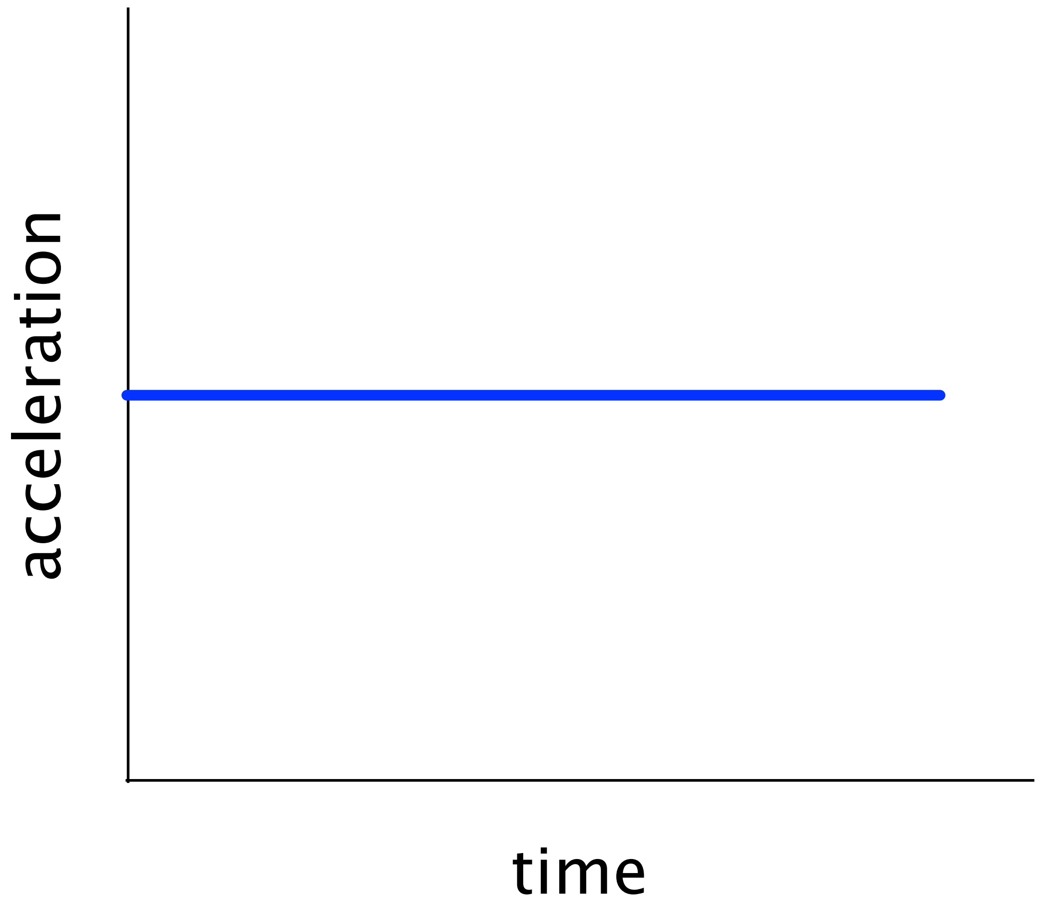


Figure 1.6 CAPM Acceleration vs. Time Graph

indicates that the velocity of the object is becoming more negative. Similarly, note that this doesn't necessarily mean that the object is moving slower. An object moving in the negative direction that experiences a negative acceleration will speed up.

Mathematical Model

The mathematical relationship between position, velocity, acceleration, and time is commonly represented with three equations for the CAPM.

$$v = v_o + at$$
$$x = x_o + v_o t + \frac{1}{2}at^2$$
$$v^2 = v_o^2 + 2a(x - x_o)$$

where x represents the position at the end of the time period (units: m); x_o, the position at the beginning of the time period; v, the velocity at the end of the time period (units: m/s); v_o, the velocity at the beginning of the time period (units: m/s); a, acceleration (units: m/s/s); and t, time (units: s).

Section 2

Motion in Two Dimensions

MOTION IN TWO DIMENSIONS

a) **Students should be able to add, subtract, and resolve displacement and velocity vectors, so they can:**
   (1) **Determine components of a vector along two specified, mutually perpendicular axes.**
   (2) **Determine the net displacement of a particle or the location of a particle relative to another.**
   (3) **Determine the change in velocity of a particle or the velocity of one particle relative to another.**

c) **Students should understand the motion of projectiles in a uniform gravitational field, so they can:**
   (1) **Write down expressions for the horizontal and vertical components of velocity and position as functions of time, and sketch or identify graphs of these components.**
   (2) **Use these expressions in analyzing the motion of a projectile that is projected with an arbitrary initial velocity.**

This section describes motion in two dimensions, including projectile motion. A new model is applicable to our study of projectile motion: projectile motion particle model (PMPM). First, .

Vectors

A vector has a magnitude and a direction. Many quantities in physics are represented as vectors (displacement, velocity, acceleration, force, momentum). Frequently when solving problems involving vectors, we need to calculate how much of the magnitude of the vector is in one direction and how much is in a perpendicular direction. This is done by breaking a vector into its components.

Vector Components

Given the velocity of a particle represented as a vector, we can calculate the components of the vector along two perpendicular axes. Figure 1.7 illustrates a velocity vector along with its horizontal and vertical components. The components are calculated:

$$v_{xo} = v_o cos(\Theta)$$

$$v_{yo} = v_o sin(\Theta)$$

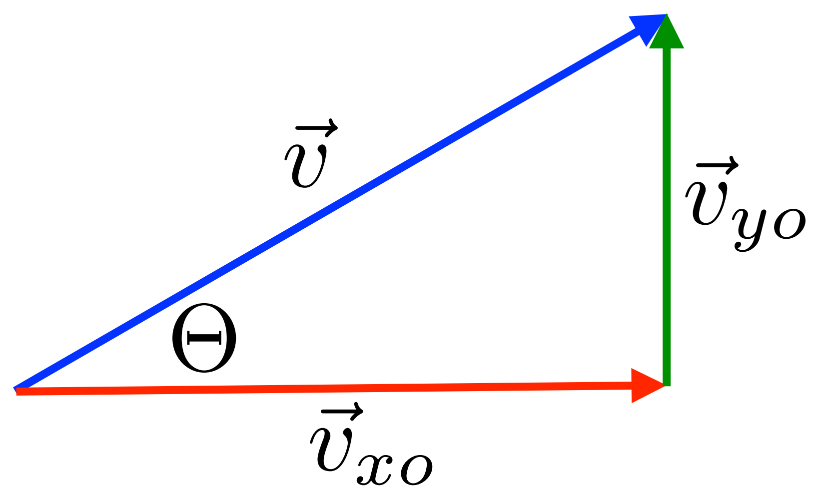


Figure 1.7 Velocity Vector Components

Breaking a vector into its components is a common step when solving kinematics, dynamics, and momentum problems.

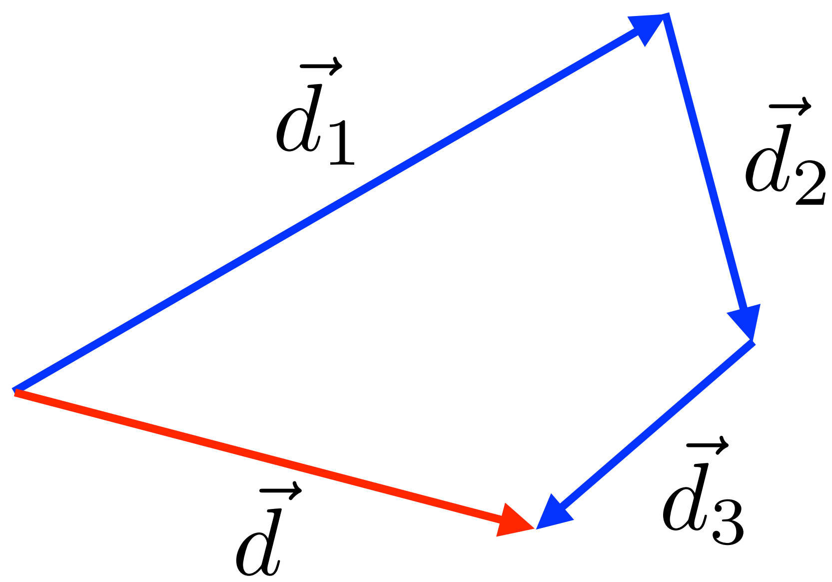


Figure 1.8 Vector Addition

Vector Addition

The sum of multiple vectors is the resultant or vector sum. Vectors can be added graphically by translating the vectors such that the tail of each subsequent vector is aligned with the head of each previous vector as shown in Figure 1.8.

$$\vec{d} = \vec{d}_1 + \vec{d}_2 + \vec{d}_3$$

Vectors can also be added by breaking each vector into its components and calculating the arithmetic sum of the components in each direction. The resultant vector is then constructed from these component sums. Common examples where vectors are added are to calculate the total displacement of the object or the velocity due to multiple factors, as in a boat moving on a river with current or a plane flying through the air with wind.

$$d_x = d_{x1} + d_{x2} + d_{x3}$$

$$d_y = d_{y1} + d_{y2} + d_{y3}$$

$$\vec{d} = \vec{d}_x + \vec{d}_y$$

Vector Subtraction

One vector can be subtracted from another by negating the second vector and adding it to the first. When a vector is negated, its magnitude remains the same and its direction is reversed. A common example of where vectors are subtracted is when calculating the velocity of one object relative to another. Figure 1.9 shows how the velocity of object A with respect to, or from the perspective of, object B is calculated.

$$\vec{v}_{AwrtB} = \vec{v}_A - \vec{v}_B$$

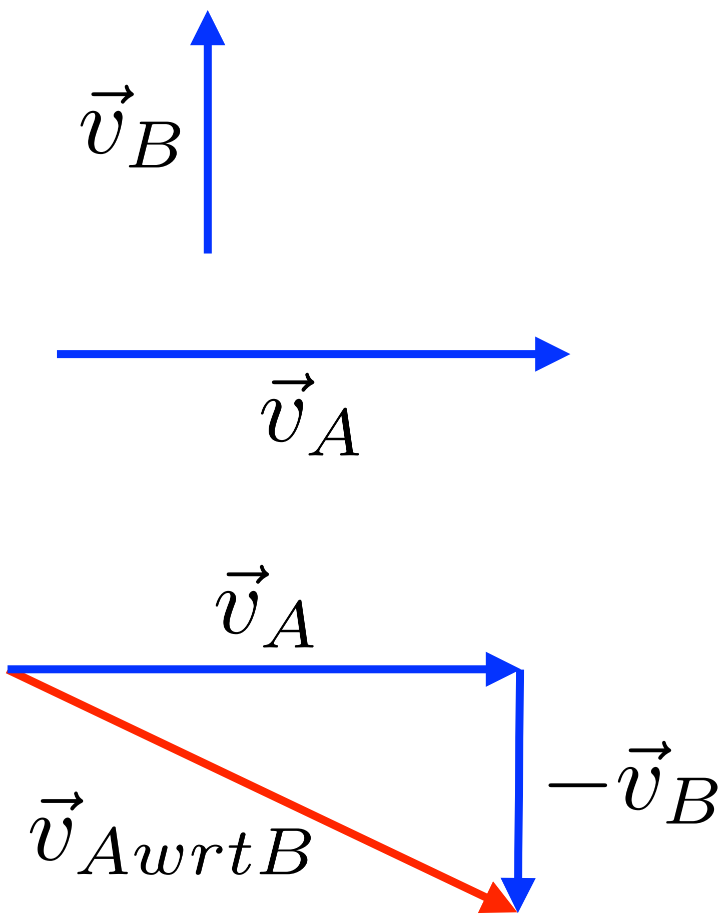


Figure 1.9 Vector Subtraction

Projectile-Motion Particle Model (PMPM)

The projectile-motion particle model (PMPM) describes the motion of a point particle accelerated due to a gravitational field. It is really a combination of the two previous models. The horizontal motion of the projectile is modeled by the CVPM and the vertical motion by the CAPM.

Constraints and Simplifications

- objects are modeled as point particles
- objects experience a constant gravitational force

Graphical Model

The CVPM is described graphically through position vs. time, velocity vs. time, and acceleration vs. time graphs. The graphs for the horizontal motion (Figure 1.10) are the same as those for CVPM with the projectile moving in the positive horizontal direction. The graphs for vertical motion (Figure 1.11) are the same as those for CAPM where the projectile has an initial positive velocity and starts and ends its motion at the zero vertical position.

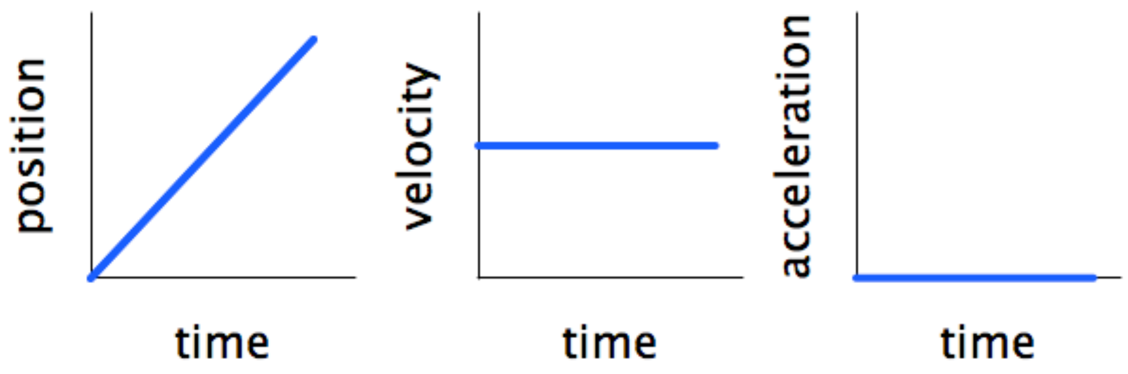


Figure 1.10 Horizontal Motion Graphs for PMPM

Diagram

A diagram of the motion of projectiles in the horizontal and vertical directions captures the initial conditions and the directions of the displacement, velocity, and acceleration. For example, in Figure 1.12, the vertical displacement is negative as the final vertical position is negative and the initial is zero. Note

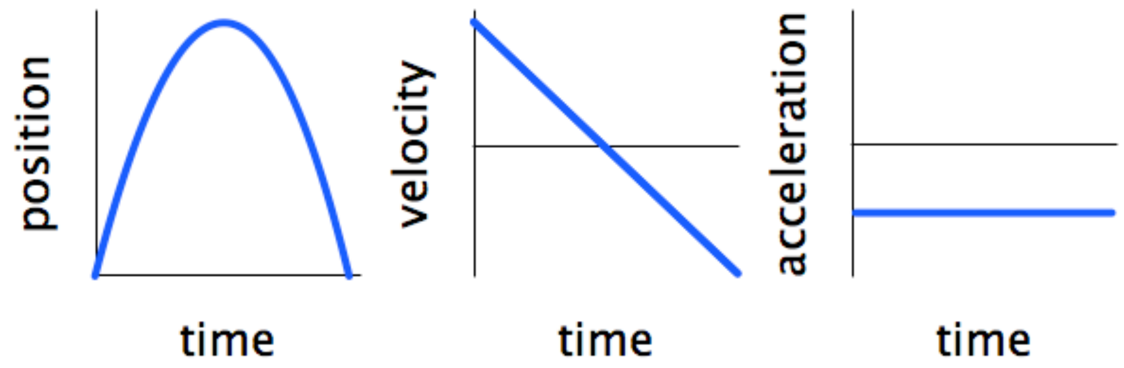


Figure 1.11 Vertical Motion Graphs for PMPM

that the positive and negative directions, both horizontally and vertically, and the origin are labeled on the diagram.

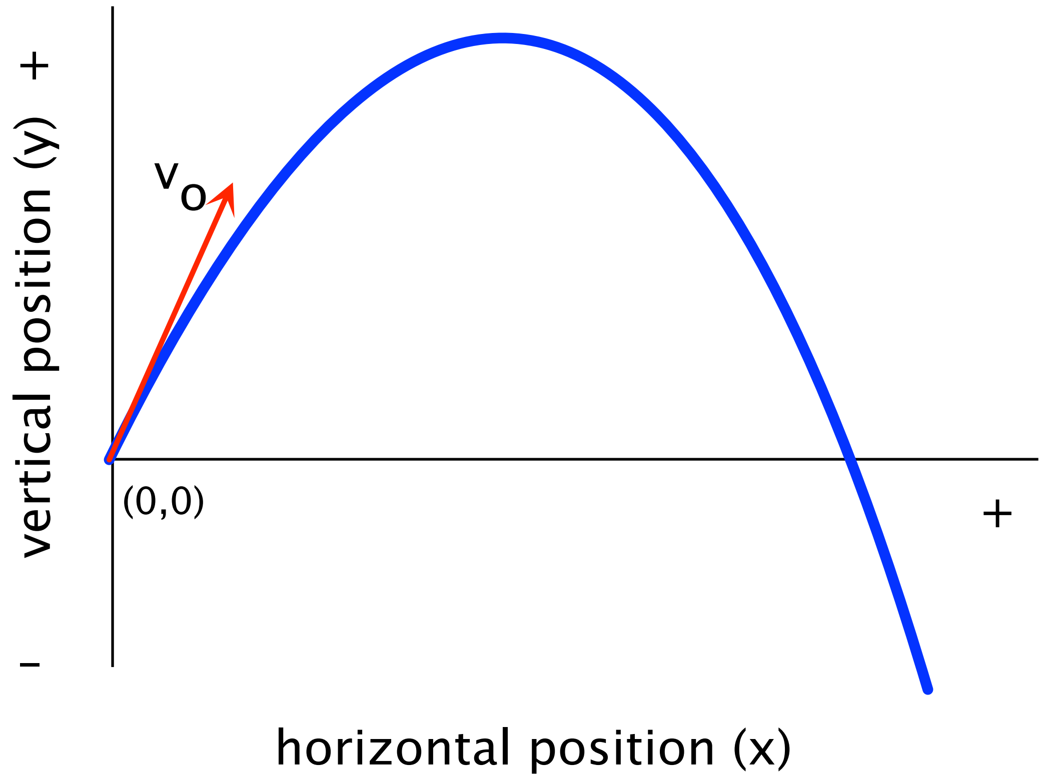


Figure 1.12 Diagram of Projectile Motion

Mathematical Model

There are no new equations related to the PMPM. When analyzing the horizontal motion of the projectile, the CVPM mathematical model is used. When analyzing the vertical motion of the projectile, the CAPM mathematical model is used. To clearly distinguish the horizontal direction from the vertical direction, we use x and x subscripts for horizontal motion and y and y subscripts for vertical motion. For example:

$$x = v_x t$$

$$v_y = v_{yo} + a_y t$$

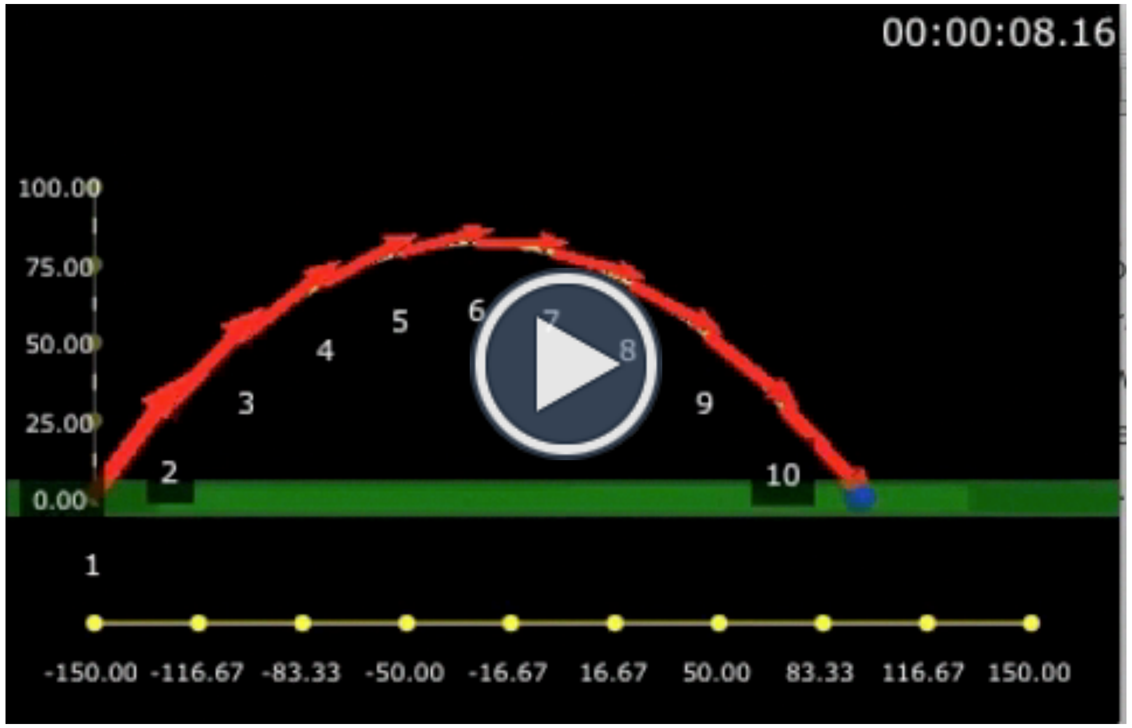
$$y = y_o + v_{yo} t + \frac{1}{2} a_y t^2$$

$$v_y^2 = v_{yo}^2 + 2a_y (y - y_o)$$

Computational Model

Movie 1.3 demonstrates a computational model for projectile motion where the vertical displacement is zero. Download the model from our class web site and modify it to model other projectile motion scenarios.

This model demonstrates how to create two axes, horizontal and vertical; how to create two plots on the same graph (horizontal position and vertical position vs. time); and how to create a two-dimensional motion map that includes velocity vectors (the red arrows).



Movie 1.3 PMPM Computational Model